

(WO/2002/027731) CABLE WITH RECYCLABLE COVERING

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Abstract:

The invention describes a cable with recyclable covering, particularly for transporting or distributing medium or high voltage energy, in which at least one covering layer is based on thermoplastic polymer material comprising a propylene homopolymer or a copolymer of propylene with ethylene or an α m(W)-olefin other than propylene in mixture with a dielectric liquid. The cable of the invention possesses superior mechanical and electrical properties, including high dielectric strength, in particular enabling it to be used at high operating temperature.

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CABLE WITH RECYCLABLE COVERING ***** The present invention relates to a cable with recyclable covering. In particular, the invention relates to a cable for transporting or distributing medium or high voltage electrical energy, wherein an extruded covering layer based on a thermoplastic polymer material in admixture with a dielectric liquid with high mechanical and electrical properties is present, enabling, in particular, the use of high operating temperatures and the transportation of high power energy.

The requirement for products of high environmental compatibility, composed of materials which, in addition to not being harmful to the environment both during production and utilization, can be easily recycled at the end of their life, is now fully accepted in the field of electrical and telecommunications cables.

However the use of materials compatible with the environment is certainly conditioned by the need to limit costs and, for the more common uses, guaranteeing a performance equivalent to or even better than that of conventional

materials anyway.

In the case of cables for transporting medium and high voltage energy, the various coverings surrounding the conductor commonly consist of polyolefin-based crosslinked polymer material, in particular crosslinked polyethylene (XLPE), or elastomeric ethylene/propylene (EPR) or ethylene/propylene/diene (EPDM) copolymers, also crosslinked. The crosslinking, effected after the step of extrusion of the polymer material on the conductor, gives the material satisfactory mechanical performance even under hot conditions during continuous use and with current overload.

It is well known however that crosslinked materials cannot be recycled, so that manufacturing wastes and the covering material of cables which have reached the end of their life can be disposed of only by incineration.

Electric cables are also known having their insulation consisting of a multi-layer wrapping of a paper or paper/polypropylene laminate impregnated with a large quantity of a dielectric liquid (commonly known as mass impregnated cables or also oil-filled cables). By completely filling the spaces present in the multi-layer wrapping, the dielectric liquid prevents partial discharges arising with consequent perforation of the electrical insulation. As dielectric liquids, products are commonly used such as mineral oils, polybutenes, alkylbenzenes and the like (see for example US-4,543,207, US- 4,621,302, EP-A-0987718, WO 98/32137).

It is however well known that mass impregnated cables have numerous drawbacks compared with extruded insulation cables, so that their use is currently restricted to specific fields of application, in particular to the construction of high and very high voltage direct current transmission lines, both for terrestrial and in particular for underwater installations. In this respect, the production of mass impregnated cables is particularly complex and costly, both for the high cost of the laminates and for the difficulties encountered during the steps of wrapping the laminate and then of impregnating it with the dielectric liquid. In particular, the dielectric liquid used must have low viscosity under cold conditions to allow rapid and uniform impregnation, while at the same time it must have a low tendency to migrate during installation and operation of the cable to prevent liquid loss from the cable ends or following breakage. In addition, mass impregnated cables cannot be recycled and their use is limited to an operating temperature less than 90°C.

Within non-crosslinked polymer materials, it is known to use high density polyethylene (HDPE) for covering high voltage cables. HDPE has however the drawback of a lower temperature resistance than XLPE, both to current overload and during operation.

Thermoplastic low density polyethylene (LDPE) insulating coverings are also used in medium and high voltage cables; again in this case, these coverings are limited by too low an operating temperature (about 70°C).

WO 99/13477 describes an insulating material consisting of a thermoplastic polymer forming a continuous phase which incorporates a liquid or easily meltable dielectric forming a mobile interpenetrating phase within the solid polymer structure. The weight ratio of thermoplastic polymer to dielectric is between 95: 5 and 25: 75. The insulating material can be produced by mixing the two components while hot either batchwise or continuously (for example by means of an extruder). The resultant mixture is then granulated and used as insulating material for producing a high voltage electric cable by extrusion onto a conductor. The material can be used either in thermoplastic or crosslinked form. As thermoplastic polymers are indicated: polyolefins, polyacetates, cellulose polymers, polyesters, polyketones, polyacrylates, polyamides and polyamines. The use of polymers of low crystallinity is particularly suggested.

The dielectric is preferably a synthetic or mineral oil of low or high viscosity, in particular a polyisobutene, naphthene, polyaromatic, *o*-olefin or silicone oil.

US 4410869 describes dielectric compositions comprising a mixture of ditolyl ether isomers, optionally in the presence of hydroquinone or a derivative thereof, used for impregnating electrical devices, including capacitors and transformers.

US 4543207 describes dielectric compositions comprising dielectric oils and aromatic mono-olefins and/or diolefins having condensed or non- condensed aromatic nuclei. Said compositions comprise, in particular, mixtures of organic acid esters, vegetable or animal oils and aromatic ethers with 0.01-50% aromatic mono-and/or diolefins having two condensed or non- condensed aromatic rings. The compositions are used to impregnate capacitors, transformers and electric cables.

The Applicant considers as still unsolved the technical problem of producing an electric cable with a covering made

from a thermoplastic polymer material having mechanical and electrical properties comparable to those of cables with an insulating covering of crosslinked material. In particular, the Applicant has considered the problem of producing a cable with a non-crosslinked insulating covering having good flexibility and high mechanical strength under both hot and cold conditions, while at the same time possessing high dielectric strength.

In view of said problem, the Applicant considers that the addition of dielectric liquids to polymer materials as proposed in the cited WO 99/13477 gives totally unsatisfactory results. In this respect, the Applicant maintains that adding a dielectric liquid to an insulating material should on the one hand determine a significant increase in its electrical properties (in particular its dielectric strength), while on the other hand maintaining the material characteristics (thermomechanical properties, manageability) unchanged, even at high operating temperature (at least 90 °C and beyond).

The Applicant has now found it possible to solve said technical problem by using, as recyclable polymer base material, a thermoplastic propylene homopolymer or copolymer mixed with a dielectric liquid as hereinafter defined. The resultant composition possesses good flexibility even when cold, excellent thermomechanical strength and high electrical performance, such as to make it particularly suitable for forming at least one covering layer, and in particular an electrical insulating layer, of a medium or high voltage cable of high operating temperature, of at least 90 °C and beyond. The dielectric liquid suitable for implementing the invention has high compatibility with the base polymer and high efficiency in the sense of improving electrical performance, consequently allowing the use of small quantities of additive such as not to impair the thermomechanical characteristics of the insulating layer.

High compatibility between the dielectric liquid and the base polymer ensures homogeneous dispersion of the liquid in the polymer matrix and improves cold behaviour of the polymer.

According to a first aspect, the invention therefore relates to a cable (1) comprising at least one electrical conductor (2) and at least one extruded covering layer (3,4,5) based on a thermoplastic polymer material in admixture with a dielectric liquid, wherein: -said thermoplastic material comprises a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an α -olefin other than propylene, said homopolymer or copolymer having a melting point greater than or equal to 140 °C and a melting enthalpy of from 30 to 100 J/g; -said dielectric liquid comprises at least one diphenyl ether, non-substituted or substituted with at least one linear or branched, aliphatic, aromatic or mixed aliphatic and aromatic C1-C30, preferably C1-C24, hydrocarbon radical.

According to a first embodiment, said extruded covering layer based on said thermoplastic polymer material in admixture with said dielectric liquid is an electrically insulating layer.

According to a further embodiment, said extruded covering layer based on said thermoplastic polymer material in admixture with said dielectric liquid is a semiconductive layer.

Preferably, the propylene homopolymer or copolymer has a melting point of from 145 to 170 °C.

Preferably, the propylene homopolymer or copolymer has a melting enthalpy of from 30 to 85 J/g.

Preferably, the propylene homopolymer or copolymer has a flexural modulus, measured in accordance with ASTM D790, at room temperature, of from 30 to 1400 MPa, and more preferably from 60 to 1000 MPa.

Preferably, the propylene homopolymer or copolymer has a melt flow index (MFI), measured at 230 °C with a load of 21.6 N in accordance with ASTM D1238/L, of from 0.05 to 10.0 dg/min, more preferably from 0.5 to 5.0 dg/min.

If a copolymer of propylene with an olefin comonomer is used, this latter is preferably present in a quantity of less than or equal to 15 mol%, and more preferably less than or equal to 10 mol%. The olefin comonomer is, in particular, ethylene or an α -olefin of formula $\text{CH}_2=\text{CH}-\text{R}$, where R is a linear or branched C2-C10 alkyl, selected for example from: 1-butene, 1-pentene, 4-methyl-1-pentene, 1-hexene, 1-octene, 1-decene, 1-dodecene and the like, or combinations thereof. Propylene/ethylene copolymers are particularly preferred.

Preferably, said thermoplastic material is selected from: (a) a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an α -olefin other than propylene, having a flexural modulus generally of from 30 to 900 MPa, preferably of from 50 to 400 MPa; (b) a heterophase copolymer comprising

a thermoplastic phase based on propylene and an elastomeric phase based on ethylene copolymerized with an α -olefin, preferably with propylene, in which the elastomeric phase is present in a quantity of at least 45 wt% on the total weight of the heterophase copolymer.

The homopolymers or copolymers of class a) show a single-phase microscopic structure, ie substantially devoid of heterogeneous phases dispersed as molecular domains of size greater than one micron. These materials do not show, in fact, the optical phenomena typical of heterophase polymer materials, and in particular are characterised by better transparency and reduced whitening due to local mechanical stresses (commonly known as "stress whitening").

Particularly preferred of said class a) is a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an α -olefin other than propylene, said homopolymer or copolymer having: a melting point of from 140 to 165 °C; a melting enthalpy of from 30 to 80 J/g; a fraction soluble in boiling diethyl ether in an amount less than or equal to 12 wt%, preferably from 1 to 10 wt%, having a melting enthalpy of less than or equal to 4 J/g, preferably less than or equal to 2 J/g; a fraction soluble in boiling n-heptane in an amount of from 15 to 60 wt%, preferably from 20 to 50 wt%, having a melting enthalpy of from 10 to 40 J/g, preferably from 15 to 30 J/g; and a fraction insoluble in boiling n-heptane in an amount of from 40 to 85 wt%, preferably from 50 to 80 wt%, having a melting enthalpy of greater than or equal to 45 J/g, preferably from 50 to 95 J/g.

Further details of these materials and their use in covering cables are given in European patent application 99122840 filed on 17.11.1999 in the name of the Applicant, incorporated herein for reference.

The heterophase copolymers of class b) are thermoplastic elastomers obtained by sequential copolymerization of : i) propylene, possibly containing minor quantities of at least one olefin comonomer selected from ethylene and an α -olefin other than propylene; and then of: ii) a mixture of ethylene with an α -olefin, in particular propylene, and possibly with minor portions of a diene.

This class of product is also commonly known by the term "thermoplastic reactor elastomers".

Particularly preferred of the said class b) is a heterophase copolymer in which the elastomeric phase consists of an elastomeric copolymer of ethylene and propylene comprising from 15 to 50 wt% of ethylene and from 50 to 85 wt% of propylene on the weight of the elastomeric phase. Further details of these materials and their use in covering cables are given in patent application WO00/41187 in the name of the Applicant, incorporated herein for reference.

Products of class a) are available commercially for example under the trademark RexflexR of the Huntsman Polymer Corporation.

Products of class b) are available commercially for example under the trademark HifaxR of Montell.

Alternatively, as thermoplastic base material, a propylene homopolymer or copolymer as hereinbefore defined can be used in mechanical mixture with a low crystallinity polymer, generally with a melting enthalpy of less than 30 J/g, which mainly acts to increase flexibility of the material. The quantity of low crystallinity polymer is generally less than 70 wt%, and preferably from 20 to 60 wt%, on the total weight of the thermoplastic material.

Preferably, the low crystallinity polymer is a copolymer of ethylene with a C₃-C₁₂ α -olefin, and possibly with a diene. The α -olefin is preferably selected from propylene, 1-hexene and 1-octene. If a diene comonomer is present, this is generally C₄-C₂₀, and is preferably selected from conjugated or non-conjugated linear diolefins, such as 1,3-butadiene, 1,4-hexadiene, 1,6-octadiene or their mixtures and the like; monocyclic or polycyclic dienes, such as 1,4-cyclohexadiene, 5-ethylidene-2-norbornene, 5-methylene-2-norbornene, 5-vinyl-2-norbornene or their mixtures and the like.

Particularly preferred ethylene copolymers are: (i) copolymers having the following monomer composition: 35-90 mol% of ethylene; 10-65 mol% of an α -olefin, preferably propylene; 0-10 mol% of a diene, preferably 1,4-hexadiene or 5-ethylene-2-norbornene (EPB and EPDM rubbers fall within this class); (ii) copolymers having the following monomer composition: 75-97 mol%, preferably 90-95 mol%, of ethylene; 3-25 mol%, preferably 5-10 mol%, of an α -olefin; 0-5 mol%, preferably 0-2 mol%, of a diene (for example ethylene/1-octene copolymers, such as the products EngageR of Dow-DuPont Elastomers).

The dielectric liquid according to the invention preferably comprises at least one diphenyl ether having the following structural formula: where R₁ and R₂ are equal or different and represent hydrogen, a phenyl group non-substituted or substituted by at least one alkyl group, or an alkyl group non-substituted or substituted by at least one phenyl.

By alkyl group it is meant a linear or branched C₁-C₂₄, preferably C₁-C₂₀, hydrocarbon radical.

Liquids advantageously usable in the present invention are for example phenyl toluyl ether, 2,3'-ditoluyli ether, 2,2'-ditoluyli ether, 2,4'-ditoluyli ether, 3,3'-ditoluyli ether, 3,4'-ditoluyli ether, 4,4'-ditoluyli ether, octadecyl diphenyl ether either as pure isomers or in mixture with each other. Said dielectric liquid has a ratio of number of aryl carbon atoms to number of total carbon atoms greater than or equal to 0.4, preferably greater than or equal to 0.7.

The diphenyl ether of the invention preferably has a dielectric constant, at 25°C, of less than or equal to 8, preferably less than 4 (measured in accordance with IEC 247).

According to a further preferred aspect, the diphenyl ether of the invention has a predetermined viscosity such as to prevent fast diffusion of the liquid within the insulating layer and hence its outward migration, while at the same time such as to enable it to be easily fed and mixed into the polymer.

Generally, the dielectric liquid of the invention has a kinematic viscosity, at 20°C, of between 1 and 100 mm²/s, preferably between 3 and 50 mm²/s (measured in accordance with ISO 3104).

According to a further preferred aspect, the diphenyl ether of the invention has a hydrogen absorption capacity greater than or equal to 5 mm³/min, preferably greater than or equal to 50 mm³/min (measured in accordance with IEC 628-A).

According to a preferred aspect, an epoxy resin can be added to the dielectric liquid suitable for forming the cable of the invention, generally in a quantity of less than or equal to 1 wt% on the weight of the liquid, this being considered to mainly act to reduce the ion migration rate under an electrical field, and hence the dielectric loss of the insulating material.

The dielectric liquid suitable for implementing the invention has good heat resistance, considerable gas absorption capacity, in particular for hydrogen, and hence high resistance to partial discharges, so that dielectric loss is not high even at high temperature and high electrical gradient. The weight ratio of dielectric liquid to base polymer material of the invention is generally between 1: 99 and 25: 75, preferably between 2: 98 and 20: 80, and more preferably between 3: 97 and 15: 85.

Dielectric liquids of the present invention can be prepared for example by reacting a cresol, in the form of a salt of an alkaline metal, with halogen toluene possibly in the presence of a copper or copper salt-based catalyst.

Further details regarding the preparation of the dielectric liquids of the invention are reported for example in US 4410869.

According to a preferred aspect, the cable of the invention has at least one extruded covering layer with electrical insulation properties formed from the thermoplastic polymer material in admixture with the aforescribed dielectric liquid.

According to a further preferred embodiment, the cable of the invention has at least one extruded covering layer with semiconductive properties formed from the thermoplastic polymer material in admixture with the aforescribed dielectric liquid. To form a semiconductive layer, a conductive filler is generally added to the polymer material. To ensure good dispersion of the conductive filler within the base polymer material, this latter is preferably selected from propylene homopolymers or copolymers comprising at least 40 wt% of amorphous phase, on the total polymer weight.

In a preferred embodiment, the cable of the invention has at least one electrical insulation layer and at least one semiconductive layer formed from a thermoplastic polymer material in admixture with a dielectric liquid as hereinabove described. This prevents the semiconductive layers from absorbing, with time, part of the dielectric liquid present in the insulating layer, so reducing its quantity just at the interface between the insulating layer and semiconductive layer, in

particular the inner semiconductive layer where the electrical field is higher.

According to a further aspect, the invention relates to a polymer composition comprising a thermoplastic polymer material in admixture with a dielectric liquid, in which: -said thermoplastic material comprises a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an α -olefin other than propylene, said homopolymer or copolymer having a melting point of greater than or equal to 140°C and a melting enthalpy of from 30 to 100 J/g; -said dielectric liquid comprises at least one diphenyl ether, non- substituted or substituted with at least one linear or branched, aliphatic, aromatic or mixed aliphatic and aromatic C1-C30, preferably C1-C24, hydrocarbon radical.

According to a further aspect, the invention relates to the use of a polymer composition, as described hereinabove, as the base polymer material for preparing a covering layer (4) with electrical insulation properties, or for preparing a covering layer (3,5) with semiconductive properties.

In forming a covering layer for the cable of the invention, other conventional components can be added to the aforedefined polymer composition, such as antioxidants, processing aids, water tree retardants, and the like.

Conventional antioxidants suitable for the purpose are for example distearylthio-propionate, pentaerythryl-tetrakis [3-(3, 5-di-tertbutyl-4- hydroxyphenyl) propionate] and 1, 3,5-trimethyl-2,4,6-tris (3,5-di-tertbutyl-4- hydroxy-benzyl) benzene and the like, or mixtures thereof.

Processing aids which can be added to the polymer base include, for example, calcium stearate, zinc stearate, stearic acid, paraffin wax and the like, or their mixtures.

With particular reference to medium and high voltage cables, the polymer materials as hereinabove defined can be advantageously used to form an insulating layer. As stated above, these polymer materials show indeed good mechanical characteristics both at ambient temperature and under hot conditions, and also show improved electrical properties, in particular they enable high operating temperature to be employed, comparable with or even exceeding that of cables with coverings consisting of crosslinked polymer base materials.

If a semiconductive layer is to be formed, a conductive filler, in particular carbon black, is generally dispersed within the polymer material in a quantity such as to provide the material with semiconductive characteristics (i. e. such as to obtain a resistivity of less than 5 Ohm. m at ambient temperature). This quantity is generally between 5 and 80 wt%, and preferably between 10 and 50 wt%, of the total weight of the mixture.

The possibility to use the same type of polymer composition for both the insulating layer and the semiconductive layers is particularly advantageous in producing cables for medium or high voltage, in that it ensures excellent adhesion between adjacent layers and hence better electrical behaviour, particularly at the interface between the insulating layer and the inner semiconductive layer, where the electrical field and hence the risk of partial discharges are higher.

The compositions of the present invention can be prepared by mixing together the base polymer material, the dielectric liquid and any other additives possibly present by methods known in the art. Mixing can be carried out for example by an internal mixer of the type with tangential rotors (Banbury) or with interpenetrating rotors, or, preferably, in a continuous mixer of Ko-Kneader (Buss) type, or of co-or counter-rotating double-screw type.

Alternatively, the dielectric liquid of the invention can be added to the polymer material during the extrusion step by direct injection into the extruder cylinder.

According to the present invention, the use of the aforedefined polymer composition in covering cables for medium or high voltage enables recyclable, flexible coverings to be obtained with excellent mechanical and electrical properties.

Greater compatibility has also been found between the dielectric liquid and thermoplastic base polymer of the invention than in the case of similar mixtures of the same polymer material with other dielectric liquids known in the art. This greater compatibility leads, inter alia, to less exudation of the dielectric liquid and hence a reduction of the already discussed migration phenomena. Because of their high operating temperature and their low dielectric loss, the cables of the invention can carry, for the same voltage, a power at least equal to or even greater than that transportable by a

traditional cable with XLPE covering.

For the purposes of the invention the term "medium voltage" generally means a voltage of between 1 and 35 kV, whereas "high voltage" means voltages higher than 35 kV.

Although this description is mainly focused on the production of cables for transporting or distributing medium or high voltage electrical energy, the polymer composition of the invention can be used for covering electrical devices in general and in particular cables of different type, for example low voltage cables, telecommunications cables or combined energy/telecommunications cables, or accessories used in constructing electrical lines, such as terminals or connectors.

Further characteristics will be apparent from the detailed description given hereinafter with reference to the accompanying drawing, in which: -Figure 1 is a perspective view of an electric cable, particularly suitable for medium or high voltage, according to the invention.

In Figure 1, the cable 1 comprises a conductor 2, an inner layer with semiconductive properties 3, an intermediate layer with insulating properties 4, an outer layer with semiconductive properties 5, a metal screen 6, and an outer sheath 7.

The conductor 2 generally consists of metal wires, preferably of copper or aluminium, stranded together by conventional methods. At least one covering layer selected from the insulating layer 4 and the semiconductive layers 3 and 5 comprises the composition of the invention as hereinbefore defined. Around the outer semiconductive layer 5 there is usually positioned a screen 6, generally of electrically conducting wires or strips wound helically.

This screen is then covered by a sheath 7 of a thermoplastic material, for example non-crosslinked polyethylene (PE) or preferably a propylene homopolymer or copolymer as hereinbefore defined.

The cable can also be provided with an outer protective structure (not shown in Figure 1) the main purpose of which is to mechanically protect the cable against impact and/or compression. This protective structure can be, for example, a metal reinforcement or a layer of expanded polymer as described in WO 98/52197.

Figure 1 shows only one possible embodiment of a cable of the present invention. Suitable modifications known in the art can evidently be made to this embodiment, but without departing from the scope of the invention.

The cable of the invention can be constructed in accordance with known methods for depositing layers of thermoplastic material, for example by extrusion. The extrusion is advantageously carried out in a single pass, for example by the tandem method in which individual extruders are arranged in series, or by co-extrusion with a multiple extrusion head.

The following examples illustrate the invention, but without limiting it.

EXAMPLES The dielectric liquids according to the invention used in the following examples were: -BaylectrolR 4900: ditoluyli ether (Bayer AG), dielectric constant at 25 °C equal to 3.5, measured in accordance with IEC 247; -NeovacR SY: octadecyl diphenyl ether (Matsumura Oil Research Corp.), dielectric constant at 25 °C equal to 2.7, measured in accordance with IEC 247.

The comparison dielectric liquids used in the following examples were: -BaysiloneRPD5 (General Electric-Bayer), dielectric constant at 25 °C equal to 2.6, measured in accordance with IEC 247; -polyphenylmethylsiloxane (PPMS), polyaromatic dielectric oil as described in IEEE Transactions on Electrical Insulation Vol. 26, No. 4, 1991), having a viscosity of 4 mm²/sec at 25 °C; -FlexonR641 (commercial product of Esso): naphthene-based aromatic oil having a viscosity of 22 mm²/sec at 40 °C, consisting of 40 wt% aromatic hydrocarbons, 57 wt% saturated hydrocarbons and 3 wt% polar compounds.

As polymer materials were used: -a flexible propylene homopolymer with melting point 160 °C, melting enthalpy 56.7 J/g, MFI 1.8 dg/min and flexural modulus 290 MPa (RexflexRWL105-commercial product of Huntsman Polymer Corp.) (Table 1, Examples 1-6) -a propylene heterophase copolymer with an ethylene/propylene elastomeric phase content of about 65 wt% (propylene 72 wt% in the elastomeric phase), melting enthalpy 32 J/g, melting point 163 °C, MFI 0.8

dg/min and flexural modulus of about 70 MPa (HifaxRKS081-commercial product of Montell) (Table 1, Examples 7-8).

Composition preparation The polymer in granular form was preheated to 80°C in a turbomixer.

The dielectric liquid was added, in the quantities specified for the formulations given in Table 1, to the polymer preheated in the turbomixer under agitation at 80°C over 15 min. After the addition agitation was continued for a further hour at 80°C until the liquid was completely absorbed in the polymer granules.

After this first stage, the resultant material was kneaded in a laboratory double-screw Brabender Plasticorder PL2000 at a temperature of 185°C to complete homogenization. The material left the double-screw mixer in the form of granules.

Measurement of dielectric strength (DS) The dielectric strength of the polymer compositions obtained was evaluated on test-pieces of insulating material having the geometry proposed by the EFI (Norwegian Electric Power Research Institute) in the publication "The EFI Test Method for Accelerated Growth of Water Trees" (IEEE International Symposium on Electrical Insulation, Toronto, Canada, June 3-6 1990). In this method, the cable is simulated with glass-shaped test pieces of insulating material having their base coated on both sides with a semiconductive material coating.

The glass-shaped test-pieces were formed by moulding discs of insulating material at 160-170°C from a plate of thickness 10 mm obtained by compressing granules at about 190°C.

The inner and outer surfaces of the base, which had a thickness of about 0.40-0.45 mm, were coated with a semiconductive coating. The DS measurement was made by applying to these specimens, immersed in silicone oil at 20°C, an alternating current at 50 Hz starting with a voltage of 25 kV and increasing in steps of 5 kV every 30 minutes until perforation of the test-piece occurred. Each measurement was repeated on 10 test-pieces. The values given in Table 1 are the arithmetic mean of the individual measured values.

TABLE 1 Ex. Polymer Dielectric % dielectric DS (mean) liquid liquid by weight 1* Reflex@-92 WL 105 2* Reflex0 Baysilone0 5 90 WL 105 PD5 3* Reflex@ Flexon@641 5 94 WL 105 4 Reflex# BaYlectrol# 6 140 WL 105 4900 5 Reflex# BaYlectrol# 13 152 WL 105 4900 6 Reflex# Neovac SY# 10 145 WL 105 7* Hifax@-90 KS081 8 Hifax# BaYlectrol# 13 140 KS081 4900 * comparison The dielectric strength values given in Table 1 highlight the improvement in electrical performance deriving from the dielectric liquids of the invention, compared to that of the base polymer as such or when mixed with the comparison dielectric liquids.

Tests on cables Cable production: The composition of the insulating layer and of the semiconductive layers is described in Table 2 below.

TABLE 2 Reference cable Cable of the (composition invention Ex 1) (composition Ex 5) Insulation Inner and Insula- Inner outer tion and semicond. outer layer semicond. layer Phr Phr Phr Phr Reflexe WL105 100 87 Baylectrolf 490013 10 Hifax KS081 100 100 Nero 55 55 Y-200 Irganoxe 1330 0. 3 0. 3 Nero Y-200: acetylene carbon black of the firm SN2A with specific surface of 70 m2/g ; IrganoxR 1330: 1, 3,5-trimethyl-2,4,6-tris (3,5-di-tertbutyl- 4-hydroxy-benzyl) benzene (Ciba Geigy).

The process used for manufacturing the cable was the following. The ReflexR WL105 and the BaylectrolR 4900, this latter with previously added IrganoxR 1330, were fed into a double-screw extruder (T=180°C) ; the mixture formed in this manner was then passed into a single-screw extruder (T=190°C, screw cross-section 150 mm2) where the filtered mixture (50 micron) feeds another extruder (screw cross-section 150 mm2, 190°C). After subsequent filtration (80 micron) the material was fed into triple head and deposited simultaneously with the semiconductive layers to form a triple layer on the metal conductor of copper plait (cross-section 400 mm2).

The cable leaving the extrusion head was fed into a tube containing silicone oil at 100°C and then into water where it was cooled to ambient temperature.

The finished cable consisted of a copper conductor (cross-section 400 mm2), an inner semiconductive layer of about 2 mm, an insulating layer of about 5.5 mm and finally an outer semiconductive layer of about 2 mm.

Under similar conditions, using the materials indicated in Table 2, a reference cable was produced.

Partial discharges: Partial discharges were measured at 20 kV/mm without encountering currents exceeding 5 pico Columb (pC) (in accordance with IEC 60-502).

Dielectric strength: 100 metres of each of the two cables produced as described above were subjected to dielectric strength measurement based on ENEL DC4584 using alternating current at ambient temperature. Starting from 30 kV/mm the gradient applied to the cables was increased by 5 kV/mm every 30 minutes until the cables perforated. The perforation gradient considered is that on the conductor.

Table 3 summarizes the data relative to the cables and the results of the electrical tests.

TABLE 3 Ex. Polymer Dielectric % dielectric DS (relative) liquid liquid by weight 1 * Rexflexe 100 WL 105 5 Reflexe 13 180 WL 105 Bayelectrolo 4900 The results obtained indicate that the cable with additives shows a DS increase of 80% over the cable without additives.

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Search
result:
1 of 1

(WO/2002/027731) CABLE WITH RECYCLABLE COVERING

- * [Biblio. Data](#)
- * [Description](#)
- * [Claims](#)
- * [National Phase](#)
- * [Notices](#)
- * [Documents](#)

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CLAIMS 1. A cable (1) comprising at least one electrical conductor (2) and at least one extruded covering layer (3,4,5) based on a thermoplastic polymer material in admixture with a dielectric liquid, wherein: -said thermoplastic material comprises a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an α -olefin other than propylene, said homopolymer or copolymer having a melting point greater than or equal to 140°C and a melting enthalpy of from 30 to 100 J/g; -said dielectric liquid comprises at least one diphenyl ether, non- substituted or substituted with at least one linear or branched, aliphatic, aromatic or mixed aliphatic and aromatic C1-C30 hydrocarbon radical.

2. A cable as claimed in claim 1, wherein the propylene homopolymer or copolymer has a melting point of from 145 to 170°C.

3. A cable as claimed in claim 1 or 2, wherein the propylene homopolymer or copolymer has a melting enthalpy of from 30 to 85 J/g.
4. A cable as claimed in any one of the preceding claims, wherein the propylene homopolymer or copolymer has a flexural modulus, measured at room temperature, of from 30 to 1400 MPa.
5. A cable as claimed in any one of the preceding claims, wherein the propylene homopolymer or copolymer has a flexural modulus, measured at room temperature, of from 60 to 1000 MPa.
6. A cable as claimed in any one of the preceding claims, wherein the propylene homopolymer or copolymer has a melt flow index, measured at 230 °C, of from 0.05 to 10.0 dg/min.
7. A cable as claimed in any one of the preceding claims, wherein the propylene homopolymer or copolymer has a melt flow index, measured at 230 °C, of from 0.5 to 5.0 dg/min.
8. A cable as claimed in any one of the preceding claims, wherein the olefin comonomer is present in a quantity of less than or equal to 15 mol%.
9. A cable as claimed in any one of the preceding claims, wherein the olefin comonomer is present in a quantity of less than or equal to 10 mol%.
10. A cable as claimed in any one of the preceding claims, wherein the olefin comonomer is ethylene or an α -olefin of formula $\text{CH}_2=\text{CH-R}$, where R is a linear or branched C₂-C₁₀ alkyl.
11. A cable as claimed in any one of the preceding claims, wherein the α -olefin is selected from 1-butene, 1-pentene, 4-methyl-1-pentene, 1-hexene, 1-octene, 1-decene, 1-dodecene and the like, or combinations thereof.
12. A cable as claimed in any one of the preceding claims, wherein the thermoplastic material is selected from: (a) a propylene homopolymer or a copolymer of propylene with at least one olefin comonomer selected from ethylene and an α -olefin other than propylene, having a flexural modulus of from 30 to 900 MPa.
(b) a heterophase copolymer comprising a thermoplastic phase based on propylene and an elastomeric phase based on ethylene copolymerized with an α -olefin, in which the elastomeric phase is present in a quantity of at least 45 wt% on the total weight of the heterophase copolymer.
13. A cable as claimed in the preceding claim, wherein the propylene homopolymer or copolymer under a) has a flexural modulus of from 50 to 400 MPa.
14. A cable as claimed in claim 12 or 13, wherein the propylene homopolymer or copolymer under a) has: a melting point of from 140 to 165 °C ; a melting enthalpy of from 30 to 80 J/g; a fraction soluble in boiling diethyl ether in an amount of less than or equal to 12 wt%, having a melting enthalpy of less than or equal to 4 J/g; a fraction soluble in boiling n-heptane in an amount of from 15 to 60 wt%, having a melting enthalpy of from 10 to 40 J/g; and a fraction insoluble in boiling n-heptane in an amount of from 40 to 85 wt%, having a melting enthalpy of greater than or equal to 45 J/g.
15. A cable as claimed in any one of claims from 12 to 14, wherein the propylene homopolymer or copolymer of a) has: a fraction soluble in boiling diethyl ether in an amount of from 1 to 10 wt%, having a melting enthalpy of less than or equal to 2 J/g; a fraction soluble in boiling n-heptane in an amount of from 20 to 50 wt%, having a melting enthalpy of from 15 to 30 J/g; and a fraction insoluble in boiling n-heptane in an amount of from 50 to 80 wt%, having a melting enthalpy of from 50 to 95 J/g.
16. A cable as claimed in claim 12, wherein the α -olefin included in the elastomeric phase of the heterophase copolymer under b) is propylene.
17. A cable as claimed in the preceding claim, wherein the elastomeric phase consists of an elastomeric copolymer of ethylene and propylene comprising from 15 to 50 wt% of ethylene and from 50 to 85 wt% of propylene on the weight of the elastomeric phase.

18. A cable as claimed in any one of the preceding claims, wherein the base thermoplastic material is the propylene homopolymer or copolymer in mechanical mixture with a low crystallinity polymer having a melting enthalpy of less than or equal to 30 J/g, and a quantity of less than or equal to 70 wt% on the total weight of the thermoplastic material.
19. A cable as claimed in the preceding claim, wherein the low crystallinity polymer is in a quantity of from 20 to 60 wt% on the total weight of the thermoplastic material.
20. A cable as claimed in claim 18 or 19, wherein the low crystallinity polymer is a copolymer of ethylene with a C3-C12 α -olefin.
21. A cable as claimed in claim 18 or 19, wherein the low crystallinity polymer is a copolymer of ethylene with an α -olefin and a diene.
22. A cable as claimed in claim 20 or 21, wherein the ethylene copolymer is selected from (i) a copolymer having the following monomer composition: 35-90 mol% of ethylene; 10-65 mol% of α -olefin; 0-10 mol% of a diene; (ii) a copolymer having the following monomer composition: 75-97 mol% of ethylene; 3-25 mol% of α -olefin; 0-5 mol% of a diene.
23. A cable as claimed in the preceding claim, wherein the ethylene copolymer is selected from a copolymer having the following monomer composition: 90-95 mol% of ethylene; 5-10 mol% of α -olefin; 0-2 mol% of a diene.
24. A cable as claimed in any one of claims from 20 to 23, wherein the α -olefin is selected from propylene, 1-hexene and 1-octene.
25. A cable as claimed in any one of claims from 20 to 24, wherein the diene has from 4 to 20 carbon atoms.
26. A cable as claimed in any one of claims from 20 to 25, wherein the diene is selected from a conjugated or non-conjugated linear diolefin, and a monocyclic or polycyclic diene.
27. A cable as claimed in any one of claims from 20 to 26, wherein the diene is selected from 1,3-butadiene, 1,4-hexadiene, 1,6-octadiene, 1,4-cyclohexadiene, 5-ethylidene-2-norbornene, 5-methylene-2-norbornene, 5-vinyl-2-norbornene, or their mixtures and the like.
28. A cable as claimed in any one of the preceding claims, wherein the hydrocarbon radical has from 1 to 24 carbon atoms.
29. A cable as claimed in any one of the preceding claims, wherein the dielectric liquid comprises at least one diphenyl ether having the following structural formula: where R1 and R2 are equal or different and represent hydrogen, a phenyl group non-substituted or substituted by at least one alkyl group, or an alkyl group non-substituted or substituted by at least one phenyl.
30. A cable as claimed in the preceding claim, wherein the alkyl group has from 1 to 20 carbon atoms.
31. A cable as claimed in any one of the preceding claims, wherein the dielectric liquid is selected from phenyl tolyl ether, 2,3'-ditolyl ether, 2,2'-ditolyl ether, 2,4'-ditolyl ether, 3,3'-ditolyl ether, 3,4'-ditolyl ether, 4,4'-ditolyl ether, octadecyl diphenyl ether either as pure isomers or in mixture with each other.
32. A cable as claimed in any one of the preceding claims, wherein the ratio of number of aryl carbon atoms to number of total carbon atoms of the dielectric liquid is greater than or equal to 0.4.
33. A cable as claimed in any one of the preceding claims, wherein the ratio of number of aryl carbon atoms to number of total carbon atoms of the dielectric liquid is greater than or equal to 0.7.
34. A cable as claimed in any one of the preceding claims, wherein the diphenyl ether has a dielectric constant, at 25 °C, of less than or equal to 8.

35. A cable as claimed in any one of the preceding claims, wherein the diphenyl ether has a dielectric constant, at 25°C, of less than or equal to 4.
36. A cable as claimed in any one of the preceding claims, wherein the dielectric liquid has a kinematic viscosity at 20°C of between 1 and 100 mm²/s.
37. A cable as claimed in any one of the preceding claims, wherein the dielectric liquid has a kinematic viscosity at 20°C of between 3 and 50 mm²/s.
38. A cable as claimed in any one of the preceding claims, wherein the diphenyl ether has a hydrogen absorption capacity of greater than or equal to 5 mm³/min.
39. A cable as claimed in the preceding claim, wherein the hydrogen absorption capacity is greater than or equal to 50 mm³/min.
40. A cable as claimed in any one of the preceding claims, wherein an epoxy resin is added to the dielectric liquid in a quantity of less than or equal to 1 wt% on the weight of the liquid.
41. A cable as claimed in any one of the preceding claims, wherein the weight ratio of dielectric liquid to base polymer material is from 1: 99 to 25: 75.
42. A cable as claimed in any one of the preceding claims, wherein the weight ratio of dielectric liquid to base polymer material is from 2: 98 to 20: 80.
43. A cable as claimed in any one of the preceding claims, wherein the weight ratio of dielectric liquid to base polymer material is from 3: 97 to 15: 85.
44. A cable as claimed in any one of the preceding claims, wherein the base polymer material is selected from propylene homopolymers or copolymers comprising at least 40 wt% of amorphous phase, on the total polymer weight.
45. A cable as claimed in any one of the preceding claims, wherein the extruded covering layer is a layer (4) with electrical insulation properties.
46. A cable as claimed in any one of claims from 1 to 44, wherein the extruded covering layer is a layer (3,5) with semiconductive properties.
47. A cable as claimed in the preceding claim, wherein a conductive filler is dispersed in the layer with semiconductive properties.
48. A cable as claimed in any one of the preceding claims, wherein at least one layer with electrical insulation properties and at least one layer with semiconductive properties are present.
49. A polymer composition comprising a thermoplastic polymer material in admixture with a dielectric liquid in accordance with any one of claims from 1 to 44.
50. Use of a polymer composition as claimed in claim 49, as base polymer material for the preparation of a covering layer (4) with electrical insulation properties.
51. Use of a polymer composition as claimed in claim 49, as base polymer material for the preparation of a covering layer (3,5) with semiconductive properties.